FACILITY ELECTRICAL AND THERMAL APPLICATIONS OF THE DOD FUEL CELL POWER PLANT FLEET

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ABSTRACT

Fuel cells are electrochemical power generators with the potential for attaining very high electrical energy conversion efficiencies while operating quietly with minimal polluting emissions. In addition, by-product thermal energy generated in the fuel cell is available for use for cogeneration of hot water or steam, bringing the overall potential conversion efficiency (electrical plus thermal) to approximately 85%. Air emissions from fuel cells are so low that several Air Quality Management Districts in the United States, including several in California which has the nation's strictest limits on air pollutants, have exempted them from requiring a permit to operate.

Under the DoD Fuel Cell Demonstration Program managed by USACERL, 200 kW Phosphoric Acid Fuel Cell (PAFC) power plants have been installed and made operational at 30 DoD sites located throughout the U.S. The electrical output from these power plants is being used to supply the adjoining facility, the distribution grid, or as a combined supply/backup source. The thermal output from these power plants is being used in a variety of building applications including heating boiler make-up water, domestic hot water, space heating water, condensate return, process hot water, etc. All of the fuel cells in the DoD fleet are being monitored for electrical and thermal efficiency, and total availability. Additionally, a subset of the DoD fleet is being monitored for pollutant emissions including NOx, SOx, CO, CO_2, total hydrocarbons, and non-methane hydrocarbons. As of February of 1998, the 30 installed PAFCs of the DoD Fleet have generated 38,538 MWh of electricity, > 58,000 MBtus of thermal energy, and saved $1,358,768 in displaced electrical and thermal energy

costs. In addition, these fuel cells have abated an estimated 9,100 tons of CO_2, 171 tons of SOx, 78 tons of NOx, and have an adjusted availability rate of 79%. Additional program and site-specific information can be found at the official website of the DoD Fuel Cell Demonstration Program, located at http://www.dodfuelcell.com.

INTRODUCTION

The principle of the fuel cell was discovered in 1839 by Sir William Grove. Fuel cells generate electricity via an electrochemical process whereby hydrogen and oxygen are combined to generate direct current (DC) electricity. NASA has used fuel cells for many years as the primary power source for space missions and they are currently employed in the Space Shuttle program. In recent years, private corporations have been working on various approaches for developing fuel cells for stationary applications in the utility, industrial, and commercial markets.

THE TECHNOLOGY

In simplest terms, a fuel cell is similar to a battery. Both operate by electrochemically converting a fuel to usable energy (electricity and heat) without the use of combustion. The main difference is that a battery has a finite supply of reactants, while in the ideal sense, fuel cells can run indefinitely as long as their reactants are replenished. Air emissions from fuel cells are so low that several Air Quality Management Districts in the United States have exempted them from requiring a permit to operate. Today's natural gas-fueled fuel cell power plants operate with an electrical conversion efficiency of 40 to 50 percent and are predicted to climb to the 50 to 60 percent in the near future. If the heat from the fuel cell is used in a cogeneration system, efficiencies can exceed 80 percent. Current conventional coal-based technologies operate at efficiencies of 33 to 35 percent.

Phosphoric Acid Fuel Cells (PAFCs) are in the initial stages of commercialization. While PAFCs are not economically competitive with other more conventional energy production technologies at the present time, current cost projections predict that PAFC systems will become economically competitive within the next few years as market demand increases.

THE FY 1993 & FY 1994 DOD FUEL CELL DEMONSTRATION PROJECTS

The FY 1993 Defense Appropriations Act provided $6.0M worth of equipment procurement funds per Service for the implementation of “non-developmental item natural gas fuel cells currently in production in the United States ... for power generation at

military installations ... with the recommendation that ... some of the cells be installed at locations in need of enhanced air quality ...". The purposes of this demonstration project are to stimulate growth in the fuel cell industry, which will lower costs through economies of scale and competition, and to determine the role fuel cells should play in DoD long-term energy supply strategy. The three Services, acting through the Defense Utilities Energy Coordinating Council (DUECC), requested that the U.S. Army Construction Engineering Research Laboratories (USACERL), a U.S. Army Corps of Engineers research laboratory affiliated with the University of Illinois at Urbana-Champaign, coordinate this fuel cell demonstration program for all three Services

A solicitation was prepared for the purchase of turnkey PAFC power plant packages, to include purchase, site engineering, installation and startup, operation and maintenance training, and a five year warranty, maintenance and repair period. Following a negotiation period, ONSI Corporation of South Windsor, CT was awarded a contract for the purchase of these turnkey PAFC systems. The terms of this contract involve cost sharing on the part of ONSI Corporation and calls for partnering with the local utility serving the selected posts. A total of 12 200-kW PAFCs were purchased with the FY 1993 Appropriations, all of which have been installed at DoD installations, with specific installation sites being identified through contract modifications.

The FY 1994 Defense Appropriations Act provided $6.25M worth of equipment procurement funds per Service "to continue procurement of nondevelopmental item (NDI) 200 kW phosphoric acid natural gas fuel cells currently in production in the United States." USACERL was again requested to coordinate this demonstration program for all three Services. Negotiations were conducted with ONSI Corporation leading to a contract for the purchase of 18 turnkey PAFC packages similar to those which were purchased with the FY 1993 Appropriation. All of the fuel cells purchased under this program have been installed and made operational as of November of 1997. (Note: $1.7M of Army funding was withdrawn from this program in June of 1996 to pay for peace keeping actions in Somalia and Haiti.)

The result of the FY 1993 and FY 1994 DoD Fuel Cell Demonstration Project efforts has been the installation of 30 PAFC plants. Tables 1 through 4 summarize the DoD PAFC fleet sites, as well as the building application, thermal application, estimated thermal utilization, and estimated annual savings for each site. Thermal utilizations were calculated from the ratio of the estimated total existing thermal load and the usable thermal output of the fuel cell. Annual savings were calculated from the sum of the estimated electric and thermal savings, minus the input natural

gas cost.

TABLE 1.

LISTING OF ARMY SITES AND APPLICATIONS FOR THE DOD PAFC FLEET

Service/ Site Name	Building Application	Thermal Application	Thermal Util.	Annual Savings
ARMY				
Ft. Bliss	Laundry	Process Hot Water	90%	$56,000
Ft. Eustis	Swimming Pool	Pool Water/DHW	55%	$35,000
Ft. Huachuca	Barracks	Space Heat/DHW	44%	$67,000
Ft. Richardson	Armory Building	Space Heat/DHW	45%	$67,000
U.S. Army Soldier Systems Command	Boiler Plant	Make-up/ Condensate	45%	$53,000
Picatinny Arsenal	Boiler Plant	Boiler Make-up Water	100%	$94,000
Pine Bluff Arsenal	Boiler Plant	Boiler Make-up Water	90%	$63,000
U.S. Military Academy	Boiler Plant	Boiler Make-up Water	70%	$30,000
Watervliet Arsenal	Central Boiler Plant	Boiler Make-up Water	58%	$76,000

TABLE 2.

LISTING OF AIR FORCE SITES AND APPLICATIONS FOR THE DOD PAFC FLEET

Service/ Site Name	Building Application	Thermal Application	Thermal Util.	Annual Savings
AIR FORCE				
911th Airlift Wing	Central Heat Plant	Space Heat	29%	$44,000
934th Airlift Wing	Boiler Plant	Make-up/ Condensate	39%	$25,000
Barksdale AFB	Hospital	Space Heat/Reheat	90%	$40,000
Davis-Monthan AFB	Gymnasium	DHW/Absorp. Chiller	65%	$61,000
Edwards AFB	Hospital	DHW/Space Heat	23%	$96,000
Kirtland AFB	Boiler Plant	Boiler Make-up Water	56%	$58,000
Laughlin AFB	Hospital	Space/Reheat/ DHW	75%	$41,000
Little Rock AFB	Hospital	Space Heat/Reheat	86%	$91,000
Nellis AFB	Dorm/Central Plant	DHW/Showers	40%	$38,000
Vandenberg AFB	Control Center	Space Heat/DHW	53%	$28,000
Westover ARB	Central Boiler Plant	Make-up/ Condensate	49%	$54,000

TABLE 3.

LISTING OF NAVY SITES AND APPLICATIONS FOR THE DOD PAFC FLEET

Service/ Site Name	Building Application	Thermal Application	Thermal Util.	Annual Savings
NAVY/MARINES				
CBC Port Hueneme	Swimming Pool	Pool	92%	$73,000
Naval Hospital MCB Camp Pendleton	Hospital	DHW	75%	$97,000
NAS Fallon	Galley	DHW	9%	$58,000
Naval Hospital NAS Jacksonville	Hospital	Space/Reheat/ DHW	9%	$90,000
Naval Education Training Center	Boiler Plant	Boiler Make-up Water	90%	$103,000
Naval Oceanographic Office, John C. Stennis Space Center	Office Building	Space Heat/ Reheat	12%	$39,000
Submarine Base Groton	Boiler Plant	Boiler Make-up Water	90%	$98,000
Naval Hospital MCAGCC Twentynine Palms	Hospital	DHW	60%	$57,000
U.S. Naval Academy	Dormitory	Kitchen DHW	70%	$38,000

TABLE 4.

LISTING OF OTHER SITES AND APPLICATIONS FOR THE DOD PAFC FLEET

Service/ Site Name	Building Application	Thermal Application	Thermal Util.	Annual Savings
OTHER				
National Defense Center for Environmental Excellence	Office/ Research Complex	Chemical Evaporator	19%	$16,000

ELECTRICAL APPLICATIONS

The ONSI PC25™ PAFC is rated to deliver 200 kW/235 kVA of electricity @ 480/277 V (3 phase). The PAFCs in the DoD Fleet are configured for one of two different modes of operation: Grid-Connected and Grid-Connected/Grid Independent.

1. Grid-Connected: The power plant is connected to the utility grid and operates unattended and automatically at a selected power level in this mode. The power plant automatically disconnects and operates in the idle mode if out-of-limits conditions occur on the utility grid. The power plant shuts down safely and automatically if any internal component malfunctions occur.

2. Grid-Connected/Grid Independent: In this configuration, the power plant is supplied with two sets of output terminals; one set connected to the utility grid and the other set connected to a dedicated load of 200 kW or less. Under normal operation the power plant supplies 200 kW to the grid as in the Grid-Connected mode. If utility power is lost, the power plant will automatically disconnect from the utility grid and supply up to 200 kW to the dedicated load, thus operating as an emergency generator. The fuel cell power output will respond automatically to load changes and fluctuations of the dedicated load. When utility power is restored, the power plant will automatically switch between output terminals and continue its normal operation of supplying 200 kW to the utility grid.

Five installations are utilizing the Grid-Connected/Grid

Independent mode of operation while two others have made provisions to use this mode in the future. Of the five utilizing this mode, two (NAS Fallon and Naval Hospital, MCAGCC Twentynine Palms) are providing emergency backup power for galleys, two (Pine Bluff Arsenal and Kirtland AFB) are providing emergency backup power for their boiler plants, and one (Ft. Eustis) is providing emergency backup power to their Field House facility, which also serves as an emergency shelter.

Since all of the fuel cells in the DoD Fleet were installed in close proximity to a facility or building in order to take advantage of thermal cogeneration, the PAFC's electrical output was often directed into the facility's 480V network through an existing or retrofitted electrical panel. Should the electrical demand of the facility fall below 200kW, the excess power is exported to the utility grid via the facility's distribution transformer. Another option for the electrical connection was to connect the PAFC's electrical output to the utility grid through an existing or retrofitted distribution transformer. The electrical output of the fuel cell is connected to the 480V (low voltage) side of a grid-connected transformer which has a rating of 300 KVA or higher. In instances where the site interface did not have an adequate 480 Volt interface, a step-up or step-down transformer was installed.

THERMAL APPLICATIONS

The ONSI PC25™ PAFC can deliver > 700,000 Btu/hr of thermal energy @ 140EF or > 350,000 Btu/hr @ 250EF and > 350,000 Btu/hr @ 140EF with the High-Grade Heat (Hot Water) option. Actual heat recovery rate is dependent upon system load, flow rate, and hot water supply and return temperatures. This available thermal energy can be used in a variety of different cogeneration applications. Excess thermal energy which is not utilized by cogeneration is directed to a cooling module which is provided with the unit.

Eleven PAFCs (37%) in the DoD Fleet are installed at central heating plants, providing hot water to preheat boiler makeup water and/or condensate return. In some cases thermal storage tanks have been installed to utilize hot water produced during times of low thermal demand. Seven PAFCs (23%) are installed at hospitals, providing hot water to preheat domestic hot water (DHW), and to supplement space heating systems and reheat cooling systems. The remainder of the fuel cells in the DoD Fleet are installed at a variety of locations including barracks, gymnasiums, office buildings, kitchens, and a laundry. Their thermal applications include preheating DHW, preheating swimming pools, and providing hot water for heating and reheat cooling systems. Of particular note is the thermal application at Davis-

Monthan AFB, where the high grade thermal output is used to provide heat to three 10 ton absorption chillers. The low grade thermal output heats an existing 1,500 gallon storage tank located in the mechanical room. The absorption chiller/PAFC application is the first of its kind in the U.S.

CONCLUSIONS

Fossil-fuel electric utilities account for two thirds of the sulfur dioxide (SO_2), one third of the nitrogen dioxide (NO_2), and one third of the carbon dioxide (CO_2) emissions in the United States.[1] Because of their electrochemical nature, fuel cell power plants are cleaner and more efficient than their combustion-based counterparts. Results from independent PAFC emissions testings have confirmed manufacturer's claims of this environmentally-friendly technology. Electrical energy conversion efficiencies of PAFCs are on the order of 40%; with the addition of thermal cogeneration overall efficiencies of greater than 80% can be achieved.

There are many electrical and thermal applications of PAFCs on DoD installations. PAFC power plants can supply 200 kW of electricity to the utility grid which offers savings by reducing both energy and demand expenditures. With the grid independent option, the power plant can provide emergency backup power to a dedicated load of 200 kW or less should the utility grid fail for any reason. By supplying waste heat to central plants, hospitals, barracks, etc., cogeneration from PAFCs can also reduce thermal energy expenditures.

As of February of 1998, the 30 installed PAFCs of the DoD Fleet have generated 38,538 MWh of electricity, > 58,000 MBtus of thermal energy, and saved $1,358,768 in displaced electrical and thermal energy costs. In addition, these fuel cells have abated an estimated 9,100 tons of CO_2, 171 tons of SOx, 78 tons of NOx, and have an adjusted availability rate of 79%. The ongoing results of this demonstration program are proving that PAFCs are a clean, efficient, reliable source of power generation and should be considered a viable alternative to conventional power-producing technologies. For further information on the DoD Fuel Cell Demonstration Program, visit the official website at http://www.dodfuelcell.com.

REFERENCES

1. Kennedy, T., Finnell, J., and Kumor, D., "Considering Environmental Costs in Energy Planning: Alternative Approaches and Implementation," Solar Engineering 1991, American Society of Mechanical Engineering, New York.

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